Psychological Research (2002) 66: 80–89
DOI 10.1007/s004260100076

ORIGINAL ARTICLE

S.W. Brown · E.D. Bennett

The role of practice and automaticity in temporal and nontemporal dual-task performance

Accepted: 16 June 2001 / Published online: 30 October 2001

Abstract Research on time and attention shows that a nontemporal task may interfere with a concurrent timing task by making time judgments shorter, more variable, and/or more inaccurate compared to timing-only conditions. Brown (1998, *Psychological Research*, *61*, 71–81) counteracted the interference effect by giving subjects automaticity training on a nontemporal task to reduce the amount of processing resources the task required. Such practice attenuated interference in timing. Two new experiments were designed to replicate and extend the previous findings. Subjects generated a series of 5-s temporal productions under single-task (timing only) and dual-task (timing plus nontemporal task) conditions. The nontemporal tasks were pursuit rotor tracking (Experiment 1), and mirror-reversed reading (Experiment 2). We employed a pretest-practice-posttest paradigm, with the practice sessions devoted to performance of the nontemporal task. Pretest-posttest comparisons showed that practice reduced interference in timing in both experiments. Dual-task probe trials were given during the practice sessions to trace the time course of the improvement in timing. The results showed that interference in timing was reduced with even small amounts of practice. The findings support the idea that timing is very sensitive to changes in the allocation of attentional resources.

Portions of this work were presented at the XIth Conference of the European Society for Cognitive Psychology, Ghent, Belgium, September 1999, and at the Eighth International Workshop on Rhythm Perception and Production, Losehill Hall, Castleton, England, August 2000.

S.W. Brown (✉) · E.D. Bennett
Department of Psychology,
University of Southern Maine,
Portland, ME 04104-9300, USA
E-mail: swbrown@usm.maine.edu

Introduction

This research is designed to counteract the ‘interference effect’ in timing. The interference effect refers to a distortion in temporal perception produced by nontemporal task demands. When subjects are asked to keep track of time (prospective timing) and also perform a concurrent nontemporal distractor task, their timing becomes very disrupted. Time judgments typically are shorter, more variable, or more inaccurate compared to control conditions without any distracting task. The interference effect is a well-established phenomenon that is produced by a wide range of nontemporal distractor tasks encompassing the motor, perceptual, and cognitive domains (for a review see Brown, 1997).

The interference effect has important implications for understanding underlying attentional processes involved in time perception. Most attentional models of timing explain the interference effect in terms of the allocation of processing resources (e.g., Brown, 1985; Hicks, Miller, Gaes, & Bierman, 1977; Thomas & Weaver, 1975; Zakay & Block, 1997). These models are based on a capacity theory of attention, which postulates the existence of a limited pool (or pools) of processing capacity (Navon & Gopher, 1979; Gopher, 1986; Wickens, 1991, 1992). This limited capacity is used to support the demands of mental workload, including perceptual judgments, response decisions, and other task requirements (Gopher & Donchin, 1986; O’Donnell & Eggemeier, 1986). Timing theorists assume that prospective timing is functionally equivalent to many other perceptual and cognitive tasks in that it is a deliberate, controlled process that requires attentional resources (Brown & West, 1990; Michon, 1972, 1985). In this view, concurrent temporal and nontemporal tasks compete for limited resources, with the result that less attention is devoted to timekeeping than otherwise would be the case. The fewer resources devoted to time, the more inaccurate and variable the time judgments.

One intriguing aspect of the capacity theory of attention involves the effects of practice. Practice on a task leads to 'automaticity', the ability to perform a skilled task using minimal or no processing resources (Brown & Carr, 1989; Logan, 1988, 1989; Wickens, 1992, pp. 383–385). Automatization occurs because the task is so well-practiced that many of its components become automatic and drop out of conscious awareness, thereby reducing capacity demands (Laberge & Samuels, 1974). Operationally, a reduction in dual-task interference following practice on one of the tasks is taken as evidence of automaticity (Ahissar, Laiwand, & Hochstein, 2001; Posner & Snyder, 1975; Schneider, 1985). A complete elimination of intertask interference is not necessary to demonstrate automaticity. Indeed, some researchers question whether total automaticity (with the task requiring zero resources) can be achieved (Ahissar et al., 2001; Ruthruff, Johnston, & Van Selst, 2001; Van Selst, Ruthruff, & Johnston, 1999). Even highly practiced motor tasks such as walking are not completely automatized (Lajoie, Teasdale, Bard, & Fleury, 1993; Pellecchia & Turvey, 2001). Most well-practiced tasks probably fall into the category of "partially automatized" tasks, which may involve some combination of automatic and controlled components (Hampson, 1989; Kahneman & Treisman, 1984). Such tasks may produce a reduction, but not elimination, of dual-task interference.

Automaticity offers a different avenue for investigating attentional resources in timing. Practice on a nontemporal task should reduce its resource demands. Therefore, if a timing task is paired with a well-practiced nontemporal task, then one should see a reduction in the interference effect (i.e., timing should be less disrupted by the nontemporal task). This hypothesis was tested in a recent study (Brown, 1998, Exp. 1) in which subjects received automaticity training by practicing a demanding perceptual-motor task (pursuit rotor tracking) over the course of several days. Such practice sharply reduced the interference effect. As shown in Table 1, variability scores on the concurrent timing task were higher before practice on the tracking task, and lower after receiving practice. This reduction in interference will be referred to as the 'attenuation effect'.

The present research is an extension of the previous work. This research is centered on two main goals: (a) replication and (b) attenuation. Given that this is a new line of research, it is important to reproduce the basic findings, and extend those findings to different subjects and different tasks. We selected two tasks involving different sets of skills. Experiment 1 was conceived as being a close replication of the previous research, and so involved a tracking task similar to that used earlier. Experiment 2 employed a reading task in an effort to generalize the results to other task domains.

Table 1 Pretest and posttest coefficient of variation scores for 5-s serial temporal productions under control (timing only) and experimental (timing + tracking) conditions. Pretest scores were obtained before practice on a tracking task and posttest scores were obtained after receiving practice. Higher scores signify greater variability [adapted with permission from Brown (1998) (Copyright 1998 by Springer)]

	Pretest	Posttest
Control	0.16	0.14
Experimental	0.27	0.20

Considering attenuation, we sought to track the time course of the attenuation effect by sampling dual-task performance at various points during the practice phase. Presumably, more practice on a task leads to more automaticity. The research may help determine how much practice on the nontemporal task is necessary to reduce interference in timing. Standard measures of timing performance represent the variability and accuracy of timing responses. Thus, we interpret any significant decrease in variability or increase in accuracy as reduced dual-task interference and evidence of automaticity.

The general method was to test subjects under both single-task conditions (involving timing only) and dual-task conditions (where the timing task and the nontemporal task were performed concurrently). We compared pretest measures of performance (before any practice) and posttest measures of performance (after receiving practice). Periodically throughout the practice phase, subjects received probe trials in which they were tested under concurrent, dual-task conditions. We anticipated that the probe trials would reveal changes in the allocation of attention to the timing task as a function of practice on the nontemporal task.

Experiment 1: Timing and tracking

The timing task was serial temporal production, in which subjects generated a continuous series of 5-s temporal intervals throughout a trial. Serial production has the advantage of providing an unobtrusive on-line index of timing, which makes it especially suitable for combination with a continuous nontemporal task (Brown, 1997; Michon, 1966; Shinohara, 1999; Zakay & Shub, 1998). Other timing methods, such as verbal estimation and reproduction, require a discrete-trials procedure. One important feature about temporal productions is that they bear an inverse relationship to other time judgment methods in that long productions are equivalent subjectively to short verbal estimations and reproductions, and vice versa (for a discussion see Brown, 1997). Thus, longer temporal productions represent an underestimation of time.

Following the original research, the nontemporal task was pursuit rotor tracking. The subjects manually tracked a target light that moved continuously along a circular track. In the earlier study, the target speed was 60 revolutions per minute (rpm); in the present experiment, we selected both slower (35 rpm) and faster (70 rpm) target speeds to broaden the range of difficulty of the task. Aside from enhancing the generality of the findings, there are two main reasons for employing tasks with different levels of difficulty. First, the effects of practice may vary with task difficulty (e.g., easy tasks may show a greater or quicker benefit from practice, compared to difficult tasks). Second, different degrees of nontemporal task difficulty may produce different degrees of interference with timing. Some studies show graded effects of interference on timing performance as a function of nontemporal task difficulty. Conditions with more interference may show less attenuation.

Method

Subjects

Forty-one students (13 males, 28 females) served as subjects in exchange for extra course credit in General Psychology classes at the University of Southern Maine. The students ranged in age from 17 to 51 years (mean 25.7 years).

Apparatus and stimuli

An Apple II-GS computer equipped with a mouse device and a Timemaster II H. O. clock card (Applied Engineering) set at an interrupt rate of 1,024 Hz was programmed to record and process timing responses and to control the trial duration. A photoelectric rotary pursuit apparatus (Lafayette Model 30013) was used for the tracking task. The pursuit apparatus was fitted with a 30.5 cm (12 inch) diameter circular template for the moving target light. The target itself measured 1.8 cm × 1.9 cm. Tracking was accomplished with a hand-held photosensitive stylus. Stylus-target contacts accumulated time on an electronic clock/counter (Lafayette Model 54035).

Design and procedure

Watches were removed prior to testing. For the timing task, subjects held a computer-linked mouse device in their non-preferred hand and were instructed to press the mouse button every 5 s. They were encouraged to be as accurate as possible in making these responses. Because different individuals may have different conceptions of what constitutes 5 s, the main focus is on the *consistency* of timing performance. As in the earlier research, subjects were not given prior training or feedback on the temporal production task. Training was restricted to the nontemporal (tracking) task. For the tracking task, the subjects held a photosensitive stylus in their preferred hand and were instructed to keep the stylus in contact with the moving target light as much as possible. The subjects were assigned randomly to the slow target ($n=21$) or fast target ($n=20$) conditions. Subjects were tested across four sessions (four different days); the sessions were separated by a week or less. Each session involved three blocks of trials, and each block in turn consisted of four 2-min trials. The computer emitted a beeping sound to signal the beginning and end of each trial.

The experiment employed a pretest-practice-posttest paradigm. On day 1, subjects received pretest blocks of trials. The pretest single-task block consisted of four trials of the timing task only, whereas the pretest dual-task block consisted of four trials of concurrent timing plus tracking. In the dual-task condition, subjects were asked to regard each task as equally important and to perform each as well as possible. The order of the single-task and dual-task blocks was counterbalanced across subjects. On day 4, subjects were tested on the posttest blocks. They received both posttest single-task (timing only) and posttest dual-task (timing + tracking) conditions. The sequence of posttest blocks was counterbalanced across subjects. Between the pretests and posttests were eight practice blocks (each consisting of four trials) spread across the 4 days of testing. It was on these trials that subjects received practice on the tracking task alone. On days 2 and 3, each practice block was followed by a dual-task probe trial. These probe trials involved concurrent timing and tracking.

Results and discussion

Timing task

Summing across all conditions and sessions, subjects made a total of 22,273 temporal productions. These responses were used to create two measures of timing performance. The first measure is the ‘coefficient of variation’ (CV), created by dividing the standard deviation by the mean. The coefficient helps control for individual differences and compensates for any directional drift in judgments across blocks of trials. Variability measures are very sensitive at detecting perturbations in timing (e.g., Casini & Ivry, 1999; Fortin, Duchet, & Rousseau, 1996). Dual-task conditions in particular are associated with increased variability, indicating that timing processes are very responsive to changes in the allocation of attentional resources (Brown, 1997; Casali & Wierwille, 1983; Vanneste & Pouthas, 1999; Wierwille, Rahimi, & Casili, 1985). The second measure is the mean ‘inter-response interval’ (IRI); i.e., the mean temporal production. These scores indicate whether there is any consistent directional error in timing. The interference effect sometimes occurs in the form of an underestimation of time. Underestimation is shown by longer temporal productions.

CV scores. CV scores were calculated for each individual by dividing the standard deviation (based upon all the responses collapsed across the four trials in a block) by the mean temporal production (computed from all the responses in a block). The scores were submitted to a 2 × 2 × 2 mixed analysis of variance (ANOVA). The factors were Attention (single-task versus dual-task), Testing (pretest versus posttest), and Target speed (slow versus fast). Attention and testing were within-subjects factors; target speed was a between-subjects factor.

The analysis uncovered significant effects for Attention, Testing, and the Attention × Testing interaction. Figure 1 shows these effects. The main effect for Attention [$F(1, 39)=71.68$, $P<0.001$] revealed a substantial difference between the single-task (mean 0.14) and dual-task (mean 0.24) conditions. This outcome corresponds to the classic interference effect. The addition of a tracking task disrupted timing by making temporal productions more variable. The Testing effect [$F(1, 39)=12.87$, $P<0.001$] is subsumed under the Attention × Testing interaction [$F(1, 39)=14.96$, $P<0.001$]. This interaction was probed with tests of simple main effects designed to compare the pretest versus posttest scores under each attention condition. As shown in Fig. 1, the pretest and posttest scores in the single-task condition are exactly the same (mean 0.14 in both cases). In the dual-task condition, there is a substantial drop in variability from the pretest (mean 0.29) to the posttest (mean 0.20) conditions [$F(1, 39)=15.98$,

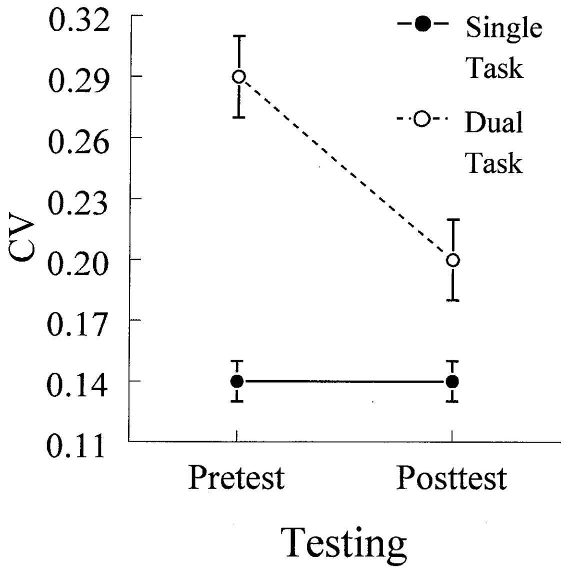

Fig. 1 Mean CV scores (and standard errors) in time judgments for single-task and dual-task conditions as a function of testing condition in Experiment 1 (CV coefficient of variation)

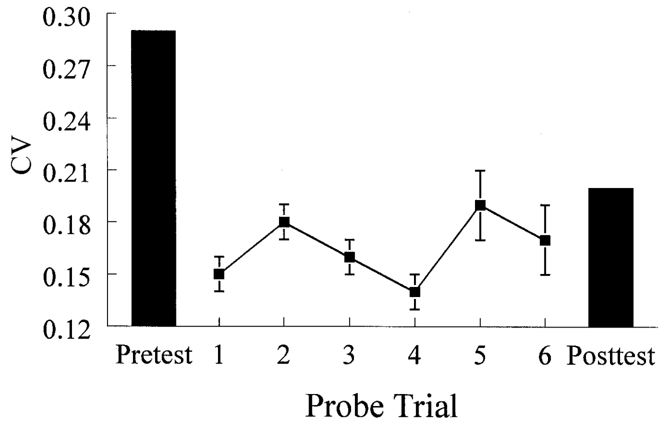

Fig. 2 Mean CV scores (and standard errors) in time judgments for the dual-task probe trials in Experiment 1. *Solid bars* represent the mean of the four trials in the pretest and posttest dual-task blocks

$P < 0.001$]. This result represents the attenuation effect. Indeed, the results are virtually identical to the results of the previous research (cf. Table 1). Figure 1 shows the standard empirical pattern that demonstrates automaticity: a well-practiced task produces less interference with a concurrent task. Practice on the tracking task allowed subjects to automatize that task (at least to a degree), so that it used fewer processing resources. More resources could be allocated to the timing task and thereby reduce error in timing. None of the other effects in the ANOVA achieved significance.

CV scores were calculated for the timing responses on the individual dual-task probe trials. These scores were submitted to a 2 × 6 (Target speed × Probe) mixed ANOVA, and the main effect for Probe [$F(5, 195) = 3.05$, $P < 0.02$] was the only significant effect. Figure 2 shows timing performance on the six probe trials. The mean scores for the comparable pretest and posttest dual-task blocks are also included in the figure to provide a frame of reference. Figure 2 suggests that there is no consistent trend in these scores, and this impression is confirmed by a series of trend analyses which failed to obtain significant effects for the linear, quadratic, or cubic components. It should be noted that the average coefficient for the six probe trials combined is 0.17, which is close to the mean posttest score of 0.20. The small amount of practice on the tracking task prior to the probe trials was all that was needed to sharply reduce dual-task interference. Note too that additional practice did not produce any further reduction in interference.

IRI scores. Mean IRI (temporal production) scores, based on all the responses in a block, were computed for each subject and submitted to a 2 × 2 × 2 (Attention × Testing × Target speed) mixed ANOVA. The Testing effect [$F(1, 39) = 20.79$, $P < 0.001$] is compounded by the Attention × Testing [$F(1, 39) = 9.74$, $P < 0.003$] interaction. The interaction was analyzed with simple main effects tests. These tests indicated that on the pretest, the two attention conditions do not differ significantly. But on the posttest, the dual-task condition (mean 5.9 s) is associated with longer productions compared to the single-task condition (mean 5.4 s); $F(1, 39) = 5.28$, $P < 0.03$. This result is consistent with studies on the interference effect which show an underestimation of time (i.e., longer productions or shorter verbal estimations and reproductions) under concurrent dual-task conditions. However, this effect is relatively weak, as it applies to the posttest only. None of the other effects were significant. IRI scores from the individual dual-task probe trials were analyzed in a Target speed × Probe mixed ANOVA; none of the effects achieved significance.

Tracking task

The standard measure of tracking performance is time-on-target (TOT), the amount of time (in seconds) the subject is able to keep the stylus in contact with the target light (Ammons, 1951; Siegel, 1990). We averaged these scores across the four trials in each block for each subject to form the basic unit of analysis. The effect of practice on single-task (tracking only) performance was evaluated first. The scores were submitted to a 2 × 8 mixed ANOVA, with the factors being Target speed (slow versus fast) and Practice (the eight practice blocks between the pretest and posttest). Both main effects were significant. As expected, the effect for Target speed [$F(1, 39) = 62.84$, $P < 0.001$] showed higher TOT scores for the slow target (mean 69.5 s) rather than the fast target (mean 46.1 s) condition. The Practice effect [$F(7, 273) = 26.42$, $P < 0.001$] indicated that performance improved across blocks. The mean scores (slow and fast targets combined) for practice blocks 1 through 8 are 51.0, 55.1, 56.1, 56.5, 62.2, 60.1, 59.7, and 63.6 s, respectively. A trend analysis uncovered a significant linear increase in these scores [$F(1, 39) = 48.31$, $P < 0.001$] which accounts for 82.6% of the variance. This improvement in performance with practice represents the development of a tracking skill. The Target speed × Practice interaction was not significant ($F < 1$).

Two additional analyses were applied to the tracking scores. The first analysis involves tracking performance in the pretest and posttest dual-task conditions. The scores were analyzed in a 2 × 2 (Target speed × Testing) mixed ANOVA. The main effect for Target speed [$F(1, 39) = 73.87$, $P < 0.001$] showed predictable differences between the slow (mean 62.7 s) and fast (mean 38.9 s) targets. The Testing effect [$F(1, 39) = 123.17$, $P < 0.001$] showed an increase in time-on-target from the pretest (mean 42.8 s) to the posttest (mean 59.5 s). This result indicates that the effects of single-task practice on tracking extended to dual-task (timing + tracking) conditions. The Target speed × Practice interaction was not significant ($F < 1$). The second analysis focused on tracking performance on the dual-task probe trials. TOT scores were submitted to a 2 × 6 (Target speed × Probe) mixed ANOVA. As expected, the Target speed effect [$F(1, 39) = 63.09$, $P < 0.001$] showed better tracking for the slow (mean 65.7 s) rather than the fast (mean 42.6 s) targets. The Probe main effect [$F(5, 195) = 11.22$, $P < 0.001$] revealed a small but steady increase in tracking performance across the six probe trials. The mean scores for probe trials 1–6 are 51.6, 51.9, 52.5, 57.4, 56.4, and 57.0 s, respectively. The linear trend [$F(1, 39) = 17.93$, $P < 0.001$] accounts for 77.8% of the variance. The interaction was not significant.

Summarizing the results of Experiment 1, the data provide a direct replication of the earlier research. Practice on the tracking task attenuated the interference effect in timing. The findings imply that the subjects had automatized the tracking task. That is, tracking used less capacity after practice than it did before. Because of this reduced demand for resources, tracking produced less interference with timing on the posttest. The probe trials revealed that the attenuation effect occurred after a relatively small amount of practice. All these results are consistent with attentional models that emphasize the role of resource allocation in time perception.

Experiment 2: Timing and reading

Experiment 2 was designed to extend the automaticity training paradigm to a different nontemporal task. The task we selected was mirror-reversed reading. Reading satisfies a number of important requirements for a nontemporal distractor task (Brown, 1997, p. 1122): (a) reading can be performed on a continuous basis, (b) it can be performed concurrently with serial temporal production, and (c) performance measures (e.g., number of words read) are readily available. Moreover, one would expect a relatively rapid development of reading skill leading to automaticity. Equally important, reading belongs to a different domain than tracking, and so could enhance the generality of the findings. Tracking is primarily a perceptual-motor task, whereas mirror-reversed reading is essentially cognitive in nature. The stimulus material consisted of mirror-reversed text in which each letter was reversed, and the text itself was read from right to left. Half the subjects had easy material to read and half had difficult material. As before, the timing task involved the serial temporal production of 5-s intervals.

Method

Subjects

Twenty-eight students (6 males, 22 females) enrolled in General Psychology classes at the University of Southern Maine participated in exchange for extra course credit. The mean age of the students was 24.0 years (range 18–35 years).

Stimuli and apparatus

The computer hardware and software were the same as used in Experiment 1. The reading material was excerpted from two sources. The easy material (mean word length 4.1 letters) was taken from a work of juvenile fiction (Sachar, 1987) written for a 10- to 12-year-old audience. The difficult material (mean word length 5.0 letters) was from a popular science book on astronomy (Comins, 1993) aimed at the educated adult lay person. The text was prepared as follows. First, extended excerpts from each book were typed into a word processor file and printed on transparencies in a Courier New, 12-point, bold font with 1-inch margins. Next, the transparencies were placed wrong-side up in a photocopier to produce pages of mirror-reversed text printed on paper.

Design and procedure

For the timing task, subjects held the mouse device in their nonpreferred hand and were asked to press the mouse button at 5-s intervals throughout a trial. For the reading task, subjects were assigned randomly to either the easy ($n = 14$) or difficult ($n = 14$) text conditions. Each subject sat at a table with a stack of pages of the mirror-reversed text, and was instructed to read the text aloud on a word-for-word basis as quickly as possible. The subjects were required to read each word correctly before they progressed to the next word, and skipping words was not allowed. The experimenter sat beside the subjects to monitor their reading performance and to ensure that they complied with the instructions. At the end of each trial, the experimenter consulted a master sheet listing a cumulative count of the words for each line of text, and recorded the exact number of words the subject had read. In the dual-task conditions, subjects were told that both tasks were equally important and that both should be performed as accurately as possible. Other than the use of mirror-reversed reading rather than tracking as the nontemporal task, the experimental design is identical to that of Experiment 1.

Results and discussion

Timing task

Subjects generated a total of 13,865 temporal productions. These responses were used to generate CV and IRI scores for analysis.

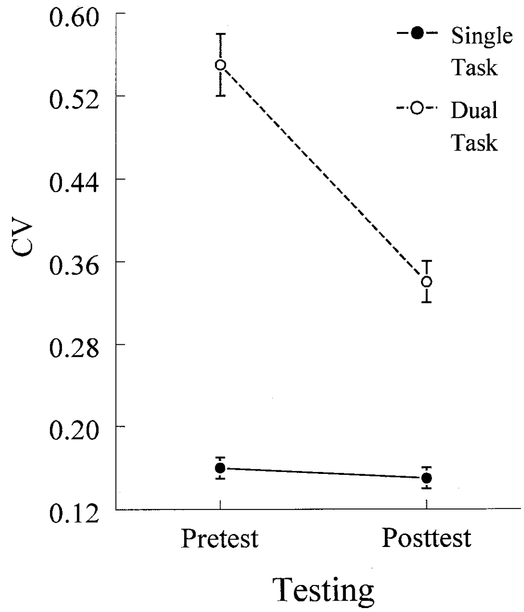

Fig. 3 Mean CV scores (and standard errors) in time judgments for single-task and dual-task conditions as a function of testing condition in Experiment 2

CV scores. CV scores were calculated for each subject by dividing the standard deviation of all the responses collapsed across the four trials in each block by the mean of the responses. These scores were submitted to a 2 × 2 × 2 mixed ANOVA, with the factors being Attention (single-task versus dual-task), Testing (pretest versus posttest), and Text (easy versus difficult). The analysis uncovered significant effects for Attention, Testing, and the Attention × Testing interaction; Fig. 3. The results are strikingly similar to those of Experiment 1. The Attention effect [$F(1, 26) = 165.92$, $P < 0.001$] showed a large difference in variability between the single-task (mean 0.16) and dual-task (mean 0.45) conditions. The reading task in the dual-task condition creates lots of interference in timing. The effect for Testing [$F(1, 26) = 32.09$, $P < 0.001$] is compounded by the Attention × Testing interaction [$F(1, 26) = 35.12$, $P < 0.001$]. Simple main effects tests indicated that the single-task pretest and posttest scores did not differ ($F < 1$). However, the dual-task scores exhibited a substantial decrease in variability from pretest to posttest [$F(1, 26) = 39.90$, $P < 0.001$]. Once again, practice on a nontemporal task reduced the interference effect. None of the other effects in the ANOVA achieved significance.

CV scores derived from each of the dual-task probe trials were submitted to a 2 × 6 (Text × Probe) mixed ANOVA[1]. The only significant result was an effect for Probe [$F(5, 125) = 2.61$, $P < 0.03$] (Fig. 4). A trend analysis showed that the quadratic trend

[1]One subject was eliminated from this analysis because of an outlier score on Probe Trial 1. The outlying CV score (4.47) is 5.5 times greater than the next highest score (0.80). The analysis is based on the responses of the remaining 27 subjects.

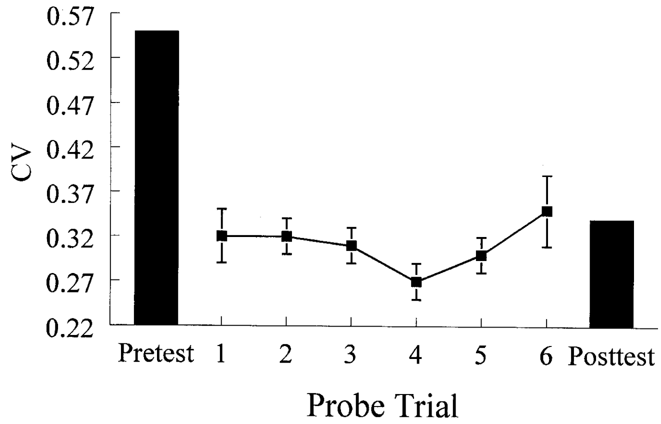

Fig. 4 Mean CV scores (and standard errors) in time judgments for the dual-task probe trials in Experiment 2. *Solid bars* represent the mean of the four trials in the pretest and posttest dual-task blocks

[$F(1, 25) = 4.35$, $P < 0.05$] accounts for 63.6% of the variance. This effect probably relates to the rise in variability on probe trial 6, possibly reflecting the effects of fatigue. The important result is that there is a sharp reduction in interference after a relatively small amount of practice on the nontemporal task, with no further improvement in performance across the six probe trials. The average coefficient for the six probe trials combined is 0.31, which is close to the mean posttest score of 0.34.

IRI scores. The mean IRI, derived from all the responses in a block, was calculated for each subject. These scores were submitted to an Attention × Testing × Text mixed ANOVA. The Attention main effect [$F(1, 26) = 14.35$, $P < 0.001$] is compounded by the Attention × Testing interaction [$F(1, 26) = 11.90$, $P < 0.002$]. Simple main effects tests indicated that the two attention conditions differed on the pretest only [$F(1, 26) = 19.82$, $P < 0.001$], with temporal productions increasing from the single-task condition (mean 4.8 s) to the dual-task condition (mean 7.1 s). This pattern is similar to that obtained in Experiment 1, except that the effect applies to the pretest rather than posttest. In both cases, the dual-task conditions yielded longer productions, signifying an underestimation of time. None of the other effects were significant. Mean IRI scores from the probe trials were submitted to a 2 × 6 (Text × Probe) mixed ANOVA, but none of the effects achieved significance.

Reading task

The dependent measure for reading performance is the number of words read during each 2-min trial. We computed the average value for the four trials per practice block and submitted these scores to a 2 × 8 (Text × Practice) mixed ANOVA. The main effect for Text [$F(1, 26) = 21.38$, $P < 0.001$] showed that more words were read in the easy (mean 167.2) than in the difficult (mean 94.3) reading conditions. The Practice

[F(7, 182) = 123.06, $P < 0.001$] and Text × Practice [F(7, 182) = 14.64, $P < 0.001$] effects also were significant. Simple main effects tests indicated that practice exerted significant effects in both the easy [F(7, 182) = 105.67, $P < 0.001$] and difficult [F(7, 182) = 32.04, $P < 0.001$] conditions. In the easy condition, the mean number of words read in practice blocks 1–8 are 93.1, 136.2, 149.6, 173.7, 172.0, 203.8, 201.2, and 207.8, respectively. A trend analysis revealed that the linear trend [F(1, 13) = 310.13, $P < 0.001$] accounts for 90.1% of the variance. In the difficult condition, the mean number of words read in practice blocks 1–8 are 64.4, 76.4, 76.0, 85.5, 101.3, 112.7, 111.9, and 125.9, respectively. The linear trend [F(7, 13) = 103.44, $P < 0.001$] accounts for 96.5% of the variance. Thus, there was a rapid and steady improvement in performance as a function of practice on each reading task.

Reading performance under dual-task conditions was evaluated with two analyses. First, the scores were formed into a 2 × 2 (Text × Testing) mixed design to assess differences in the dual-task pretest and posttest conditions. The Text main effect [F(1, 26) = 20.25, $P < 0.001$] showed expected differences in performance for the easy (mean 154.2) and difficult (mean 88.7) reading conditions. The effect for Testing [F(1, 26) = 201.61, $P < 0.001$] uncovered a large improvement in performance between the pretest (mean 72.4) and posttest (mean 170.6). The Text × Testing interaction [F(1, 26) = 13.59, $P < 0.001$] was subjected to tests of simple main effects. The tests showed that more words were read in the easy rather than difficult condition on both the pretest [F(1, 26) = 13.13, $P < 0.001$] and posttest [F(1, 26) = 20.82, $P < 0.001$]. Also, more words were read on the posttest compared to the pretest for both the easy [F(1, 26) = 159.93, $P < 0.001$] and the difficult [F(1, 26) = 55.26, $P < 0.001$] text conditions. A second analysis concentrated on reading performance on the dual-task probe trials. Reading scores associated with the two texts and six probe trials were submitted to a 2 × 6 mixed ANOVA, and both main effects were significant. Consistent with the previous analysis, the main effect for Text [F(1, 26) = 31.75, $P < 0.001$] showed that more words were read in the easy (mean 174.5) rather than the difficult (mean 91.2) condition. The main effect for Probe [F(5, 130) = 37.51, $P < 0.001$] showed that single-task practice on the reading task carried over to reading performance under dual-task conditions. The mean reading scores for probe trials 1 through 6 are 115.2, 106.3, 118.5, 146.2, 151.2, and 159.6, respectively. A trend analysis revealed a linear increase in scores [F(1, 26) = 195.97, $P < 0.001$], accounting for 86.1% of the variance. The interaction was not significant.

Experiment 2 indicated that practice on the reading task significantly reduced the degree to which the task interfered with concurrent timing. Dual-task probe trials showed that this attenuation effect was achieved after a small amount of practice. Reading performance improved throughout the practice phase, in both single-task and dual-task (probe) conditions.

General discussion

The two experiments produced a remarkably consistent pattern of results. In both cases, practice on a nontemporal task produced clear evidence of the attenuation effect, a reduction in interference in timing from a concurrent nontemporal distractor task. This same result occurred despite the fact that the nontemporal tasks – pursuit-rotor tracking and mirror-reversed reading – have very different requirements and probably rely on different sets of cognitive mechanisms. The results point to the attenuation effect as a solid, replicable finding which generalizes to different nontemporal distractor tasks (see also Sawyer, 1999). Further, the present data replicate the key findings from the previous research (Brown, 1998, Exp. 1). It is instructive to compare the amount of reduction in interference in the three studies. This information can be obtained by calculating the percentage by which coefficient of variation scores declined from the dual-task pretest to the dual-task posttest. In Brown (1998), the figure is 25.9%, and in the present Experiment 1 the corresponding value is 31.0%. Both these studies employed a tracking task and produced comparable results. The attenuation effect was even greater for the reading task used in Experiment 2, where timing variability underwent a 38.2% reduction from pretest to posttest. Experiment 2 may have produced a stronger attenuation effect because reading may share many of the resources associated with timing. Tracking relies on visual and motor processing, whereas reading is more central, requiring a greater involvement of cognitive processes specialized for word identification and sentence comprehension. The results fit with previous research (Brown, 1997) suggesting that timing is primarily a central executive function, drawing upon the same attentional resources used for reasoning, decision making, and language processing (Baddeley, 1990).

The data lend themselves to a straightforward interpretation based on changes in resource allocation as a consequence of automaticity. Practice on a task leads to a shift in cognitive processing such that the task uses fewer attentional resources as various components of performance (e.g., stimulus analysis, response decisions, the coordination of different task elements, etc.) become automatized. The less attention needed by the automatized nontemporal task, the more attention available for the concurrent timing task and hence an improvement in timing performance. This reallocation of resources to timing reduces the interfering effects of the nontemporal task. A complication is that the different levels of task difficulty did not produce differential effects on timing performance, an outcome often observed in the timing interference literature. One explanation is that timing is extremely sensitive to cognitive demands, and that even light processing loads may cause considerable disruption in timing performance (Brown, 1997, p. 1136). Hence both easy and difficult versions of a task may create maximum interference in timing. It may be more of a challenge to devise nontemporal tasks that produce only small amounts of interference.

It might be argued that timesharing, rather than automaticity, is the mechanism responsible for the attenuation effect. Timesharing refers to a rapid switching of attention between two or more tasks (Abernethy, 1988; Hirst & Kalmar, 1987). In this account, practice on the nontemporal task produces greater familiarity and skill on the task that allows for more efficient timesharing between concurrent temporal and nontemporal tasks on the posttest. However, this description seems unlikely in light of the previous data. In Brown (1998), a second experiment was conducted in which subjects were given extensive practice under dual-task (timing + nontemporal task) conditions. In contrast to single-task practice which is designed to promote automaticity, dual-task practice is thought to promote timesharing skills (Brown & Carr, 1989; Wickens, 1992, p. 383). However, the results showed no evidence of the attenuation effect. The nontemporal task interfered with timing on the posttest as much as it did on the pretest. Only automaticity (single-task) training appears to reduce interference in timing.

A related possibility is that the attenuation effect is due to the development of a strategy whereby subjects use temporal cues associated with the nontemporal task as an aid in making timing responses. That is, subjects learn to coordinate timing responses with certain rhythmical properties of the nontemporal task. The rapid development of such a strategy could account for why only a small amount of practice reduces interference. However, certain points speak against the coordination hypothesis. First, consider the target revolutions in the tracking task. In the prior research (Brown, 1998), the target moved at a rate of 60 rpm, which corresponds to exactly 5 revolutions every 5 s. But in the present Experiment 1, the 35 rpm condition requires 2.92 complete revolutions to equal 5 s, and the 70 rpm condition requires 5.84 revolutions. Despite these variations in target/timing compatibility, the experiments produced comparable results. Second, Experiment 2 involved a reading task in which there was no external pacing of any sort. Yet the two experiments were very similar in outcome. Third, the rapid development of a coordination strategy should be reflected in an improvement of timing performance across the four trials of the pretest dual-task condition. The mean CV scores for trials 1–4 in Experiment 1 are 0.18, 0.20, 0.22, and 0.22, respectively. If anything, these scores show an increase in variability, not the decrease predicted by a coordination hypothesis. The corresponding scores in Experiment 2 are 0.45, 0.53, 0.56, and 0.47, for trials 1–4, respectively. Again, there is no evidence for the development of a dual-task coordination strategy in these data.

The results offer some surprises with respect to the development of automaticity, and point to some directions for future research on practice, interference, and the attenuation effect. The findings raise interesting questions involving both the early and later stages of practice on the nontemporal task. Turning first to the early stages, our results demonstrate that just a small amount of practice substantially reduced the interference effect. We observed improvement in timing performance even on Probe Trial 1. This finding was unexpected, as we had anticipated that several practice blocks would be necessary to minimize interference in timing. But given the rapid improvements in nontemporal task performance (see below), attenuation was manifested in short order and remained at a maximum level throughout the testing sessions. There were eight practice trials (two blocks) on the nontemporal task prior to Probe 1, and so that is where automaticity developed. Therefore, in future experiments it would be prudent to insert probe trials early in the practice phase. Earlier probes may reveal a more progressive reduction in the interference effect. The later stages of practice also offer intriguing avenues for investigation. We found that practice on a nontemporal task *reduced* the interference effect – but it did not *eliminate* interference. Even on the posttest, there was still more timing variability in the dual-task condition compared to the single-task condition. The same pattern occurred in the earlier research as well (see Table 1). Would more practice further reduce the amount of interference? Can interference be reduced to the point where there is no difference in timing performance under single-task and dual-task conditions? These are important issues that have implications both for theoretical mechanisms underlying timing processes and for more practical concerns involving performance limitations and applied cognitive psychology.

Practice on a task also leads to an improvement in overall performance as the person acquires appropriate task-relevant skills. But as the data show, an increase in skill need not necessarily lead to a corresponding reduction in dual-task interference. A skill may exhibit measurable improvement before certain critical components or stages have become automatized (Wickens, 1992). Performance of the nontemporal tasks under single-task conditions showed a steady linear improvement across the practice blocks in both experiments. Two different sets of analyses also showed this same improvement under dual-task conditions. First, nontemporal task performance increased substantially from the dual-task pretest to the dual-task posttest. Thus we find that the nontemporal tasks produced less interference with the concurrent timing task, while at the same time the overall performance level of the nontemporal tasks improved. Second, nontemporal task performance in both experiments exhibited a steady improvement across the six dual-task probe trials. These results indicate that as subjects acquired skill on the nontemporal tasks via single-task practice, task performance continued to show improvement under dual-task conditions as well. However, the addition of a concurrent timing task tended to exert negative effects on nontemporal task performance. A simple ‘concurrence cost’ (Navon & Gopher, 1979) of dual-task performance was analyzed by calculating the difference between nontemporal task performance on each dual-task probe trial and the average performance score obtained from the practice block of trials immediately preceding it. These difference scores may be expressed as a percentage change from single-task (practice) to dual-task (probe) conditions. For Experiment 1, each of the six probe trials was associated with a decrease in tracking performance relative to the practice block; the difference scores in time-on-target averaged –6.9%. The comparable values in Experiment 2 were less consistent. Half of the difference scores showed decreases in the number of words read, and half showed increases, with the average being –0.3%. The fact that concurrent timing produced any decline in nontemporal task performance supports the idea that timing itself is an attentional task that requires processing resources.

References

Abernethy, B. (1988). Dual-task methodology and motor skills research: some applications and methodological constraints. *Journal of Human Movement Studies*, *14*, 101–132.

Ahissar, M., Laiwand, R., & Hochstein, S. (2001). Attentional demands following perceptual skill training. *Psychological Science*, *12*, 56–62.

Ammons, R. B. (1951). Effect of distribution of practice on rotary pursuit "hits." *Journal of Experimental Psychology*, *41*, 17–22.

Baddeley, A. (1990). *Human memory: Theory and practice*. Boston: Allyn & Bacon.

Brown, S. W. (1985). Time perception and attention: the effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception and Psychophysics*, *38*, 115–124.

Brown, S. W. (1997). Attentional resources in timing: interference effects in concurrent temporal and nontemporal working memory tasks. *Perception and Psychophysics*, *59*, 1118–1140.

Brown, S. W. (1998). Automaticity versus timesharing in timing and tracking dual-task performance. *Psychological Research*, *61*, 71–81.

Brown, S. W., & West, A. N. (1990). Multiple timing and the allocation of attention. *Acta Psychologica*, *75*, 103–121.

Brown, T. L., & Carr, T. H. (1989). Automaticity in skill acquisition: mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 686–700.

Casali, J. G., & Wierwille, W. W. (1983). A comparison of rating scale, secondary-task, physiological, and primary-task workload estimation techniques in a simulated flight task emphasizing communications load. *Human Factors*, *25*, 623–641.

Casini, L., & Ivry, R. B. (1999). Effects of divided attention on temporal processing in patients with lesions of the cerebellum or frontal lobe. *Neuropsychology*, *13*, 10–21.

Comins, N. F. (1993). *What if the moon didn't exist? Voyages to earths that might have been*. New York: Harper Collins.

Fortin, C., Duchet, M.-L., & Rousseau, R. (1996). Tapping sensitivity to processing in short-term memory. *Canadian Journal of Experimental Psychology*, *50*, 402–407.

Gopher, D. (1986). In defence of resources: on structures, energies, pools and the allocation of attention. In G. R. J. Hockey, A. W. K. Gaillard, & M. G. H. Coles (Eds.), *Energetics and human information processing* (pp. 353–371). Dordrecht, The Netherlands: Martinus Nijhoff.

Gopher, D., & Donchin, E. (1986). Workload – an examination of the concept. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance: Vol. II. Cognitive processes and performance* (pp. 41.1–41.49). New York: Wiley.

Hampson, P. J. (1989). Aspects of attention and cognitive science. *Irish Journal of Psychology*, *10*, 261–275.

Hicks, R. E., Miller, G. W., Gaes, G., & Bierman, K. (1977). Concurrent processing demands and the experience of time-in-passing. *American Journal of Psychology*, *90*, 431–446.

Hirst, W., & Kalmar, D. (1987). Characterizing attentional resources. *Journal of Experimental Psychology: General*, *116*, 68–81.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 29–61). New York: Academic Press.

Laberge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology*, *6*, 293–323.

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Experimental Brain Research*, *97*, 139–144.

Logan, G. D. (1988). Automaticity, resources, and memory: theoretical controversies and practical implications. *Human Factors*, *30*, 583–598.

Logan, G. D. (1989). Automaticity and cognitive control. In J. S. Uleman & J. A. Bargh (Eds.), *Unintended thought* (pp. 52–74). New York: Guilford.

Michon, J. A. (1966). Tapping regularity as a measure of perceptual motor load. *Ergonomics*, *9*, 401–412.

Michon, J. A. (1972). Processing of temporal information and the cognitive theory of time experience. In J. T. Fraser, F. C. Haber, & G. W. Muller (Eds.), *The study of time* (pp. 242–258). New York: Springer.

Michon, J. A. (1985). The compleat time experiencer. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 20–52). New York: Springer.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review*, *86*, 214–253.

O'Donnell, R. D., & Eggemeier, F. T. (1986). Workload assessment methodology. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance: Vol. II. Cognitive processes and performance* (pp. 42.1–42.49). New York: Wiley.

Pellecchia, G. L., & Turvey, M. T. (2001). Cognitive activity shifts the attractors of bimanual rhythmic coordination. *Journal of Motor Behavior*, *33*, 9–15.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Ruthruff, E., Johnston, J. C., & Van Selst, M. (2001). Why practice reduces dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 3–21.

Sachar, L. (1987). *There's a boy in the girls' bathroom*. Santa Barbara, CA: Cornerstone Books.

Sawyer, T. F. (1999). Allocation of attention and practice in the production of time intervals. *Perceptual and Motor Skills*, *89*, 1047–1051.

Schneider, W. (1985). Training high-performance skills: fallacies and guidelines. *Human Factors*, *27*, 285–300.

Shinohara, K. (1999). Resource for temporal information processing in interval production. *Perceptual and Motor Skills*, *88*, 917–928.

Siegel, B. (1990). A multivariate study of pursuit rotor skill development. *Research Quarterly for Exercise and Sport*, *61*, 201–205.

Thomas, E. A. C., & Weaver, W. B. (1975). Cognitive processing and time perception. *Perception and Psychophysics*, *17*, 363–367.

Van Selst, M. A., Ruthruff, E., & Johnston, J. C. (1999). Can practice eliminate the psychological refractory period effect? *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1268–1283.

Vanneste, S., & Pouthas, V. (1999). Timing in aging: the role of attention. *Experimental Aging Research*, *25*, 49–67.

Wickens, C. D. (1991). Processing resources and attention. In D. L. Damos (Ed.), *Multiple-task performance* (pp. 3–34). London: Taylor & Francis.
Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: Harper Collins.
Wierwille, W. W., Rahimi, M., & Casili, J. G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. *Human Factors*, *27*, 489–502.
Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science*, *6*, 12–16.
Zakay, D., & Shub, J. (1998). Concurrent duration production as a workload measure. *Ergonomics*, *41*, 1115–1128.